FACT SHEET 03-02 8-28-03

Dam Safety: Geological Considerations

Geological Setting

The geological setting is very important factor when designing or inspecting dams. It is crucial that the inspector fully understand the geological features and conditions of the site to better assess problems and deficiencies. For example, a dam located in a glacial outwash area is likely to be sitting on permeable granular materials, which would tend to transmit water (seepage) in the foundation and abutment areas.

Site-specific information obtained from a geotechnical exploration program will better define and qualify the subsurface conditions in a given geological setting. For example, a dam located in a karst geological setting will require subsurface exploration data to better define the physical parameters and extent of the typical solution features (voids and joint openings) in the foundation, abutment and spillway areas of the structure.

All dams should be assessed in light of both the local site and regional geological conditions. In addition to knowing the construction history of the dam and appurtenant structures, the inspector or the inspection team should have knowledge of the potential geologic factors that may influence the performance and safety of an existing dam.

Indiana dams typically consist of embankments made of earth materials over soil or rock foundations with auxiliary channel spillways through natural ground. As such, dams in specific regions tend to have similar characteristic or potential problems, some of which were not considered in the original design but later emerged as geologic hazards.

Many existing dams were constructed without appropriate methods and/or components to adequately address the existing geologic materials or the geologic conditions. Some of the dam safety deficiencies, as listed below, are a result of the dam builder not recognizing the physical characteristics and technical problems of certain geologic materials/conditions and implementing an appropriate design to mitigate the problems.

- Settlement, instability and/or cracking of the dam may reflect weak foundation conditions or unsuitable soil materials in the embankment.
- Seepage and/or leakage at the downstream toe or abutment/groin areas are frequently associated with the permeability characteristics of the underlying bedrock or soil.
- Natural hazards such as landslides, subsidence, and seismic events may quickly cause a component of the dam to fail leading to an uncontrolled breach.

Physiographic Divisions

Indiana is located within the Central Lowland Province, which consists of gently sloping and nearly flat-lying bedrock overlain with glacial materials in about two-thirds of the state. The State lies over a broad crested structural area, known as an anticline, trending northwest to southeast, which separates the Michigan Basin on the north from the Illinois Basin on the southwest.

The Indiana Geological Survey (IGS) has further divided the state into physiographic regions and divisions to better group landscapes of similar features (see Figure 1, Physiographic Divisions of Indiana). There are twenty three (23) distinct Physiographic Divisions in Indiana.

Some of the geologic factors for each Physiographic Division that may influence the integrity, safety, upgrade and operation of an existing dam are shown in the attached table. Although general, Physiographic Divisions do provide the framework for a better understanding of the most common, known problematic aspects or geologic hazards associated with various areas in the State.

It is important to note that the division boundaries are not finite, and dam locations near boundaries may have geologic factors associated with both divisions. Further, the geologic factors presented for a given division are indicators and will not be an issue at every existing dam site in a given region.

As more performance records and experience are obtained on dams in the Physiographic Divisions, the geologic factors will be updated. To that end, the dam inspector should have an understanding of geologic factors that may influence the safety of an existing dam or consult with a licensed professional geologist for a report on the local condition for a specific site.

Figure 1 contains a physiographic map of Indiana which shows regional geologic conditions. Table 1 may help define potential conditions which may be present based on the physiographic region where the dam is located. This information can be useful for evaluating dam seeps, foundation, or settlement issues and should be checked before the field inspection is performed. If no other local or regional geological data is available, Figure 1 and Table 1 can be used to help define potential conditions at the dam site.

Glacial Control

The east and west flanks of the southern half of the state and the entire northern half of the state are overlain by tens to hundreds of feet of unconsolidated sediments. These accumulations of till and outwash filled the bedrock valleys and covered the bedrock hills to produce the flat terrain in the central and hilly landscapes in the northern parts of the state.

Till and stratified drift from continental glaciation is so extensive in Indiana that over half of the existing dams in the state are made of soil and located on materials deposited and/or altered by ice advances and retreats. A basic understanding of glacial geology at a dam site will allow the inspector or inspection team to establish a more complete assessment of observed dam safety deficiencies and develop recommendations appropriate to improve the safety of the structure.

The large flat to gently rolling surface across the central portion of the state is referred to as the **Central Till Plain Region** (see Figure 1). Sediments laid down by the ice sheets were deposited as till (an unsorted mixture of sand, silt, clay and boulders) when the glaciers advanced into Indiana and stratified drift (i.e. outwash sand and gravel) when the ice mass retreated.

Glacial till typically provides suitable foundations and embankments for dams when properly excavated, placed and compacted. The permeable outwash materials found in the numerous glacial drainageways, however, present a problem for seepage control in the foundation and abutment areas for dams.

The **Northern Moraine and Lake Region** includes tracts of lake plains, large outwash areas, and extensive topographic morainal features (i.e. mounds, ridges or other distinct accumulations of unsorted, unstratified drift or glacial till). This region also includes sand dunes, alluvial fans, stratified drift, peat bogs and most of Indiana’s natural lakes.

The Northern Moraine and Lake Region can be a complex area to design and maintain a safe dam. The watersheds may include natural retention basins and the ground water regime may contribute significantly to the inflow quantities.

With the extensive permeable soils in this region, some dams consist of sand and gravel. Further, the soft lacustrine and peat deposits present settlement and stability problems for embankment and spillway foundations.

Glacial and Bedrock Control (Transition Area)

The Southern Hills and Lowland Region, in the lower portion of the state, has not been profoundly affected by the latest (Wisconsin) glaciation and the bedrock is at or near the surface in much of the region. The topography and drainage pattern of this region generally reflects the underlying bedrock control. There are several hundred existing dams in this region with a few structures exceeding 100 feet in height.

Other glacial events, however, did alter land features in a transition area between the southern limit of Wisconsin glacial deposits to the southern limit of older glacial deposits. This area typically has the most complex site conditions for southern Indiana since the natural physical features that influence the safety of the dam consists of deposits and alterations from glaciation in combination with the structural discontinuities and characteristics of the near surface bedrock.

Buried glacial bedrock valleys, bedrock joints, rock type and other subsurface irregularities at the dam site present unique challenges for the inspector in evaluating seepage and stability issues.

Although present throughout the state, extensive silt deposits known as loess exist in this inter-glacial transition area. Loess is a wind deposit from large glacial outwash plains. Silt is a poor material for embankment dams and foundations. The inspector should be concerned about stability and erosion in dams and channel spillways constructed with significant silt content.

Bedrock Controlled

Although bedrock may influence the performance of a dam anywhere in the state, the predominate area where bedrock is likely to present problems with water impoundment structures is southern Indiana.

The distinctly bedrock-controlled area south of the southern limit of older glacial deposits consists of sedimentary rock such as limestone, dolomite, shale, sandstone and siltstone. Shale tends to weather and erode to produce slopes where as the more weather resistant rock such as siltstone and sandstone will be found in ridges and hilltops. The weathering of limestone (also dolomite to a lesser extent) by acid dissolution produces sink holes, caves and other features known as karst.

The topography and steepness of slopes of this area vary dramatically as the bedrock type, age and characteristic changes from east to west. The typical thin residual soil layer over the bedrock could indicate that adequate foundation/abutment preparation may not have been accomplished in the construction of the dam and seepage paths may have been developed if the soil was stripped off of the bedrock near the dam for borrow material.

The regional and local rock mass properties of sedimentary rock have a significant influence on the construction of the dam in addition to the long term performance of the structure. The surface and subsurface movement of water is strongly controlled by orientation of the joints in the sedimentary rock.

Seismic

Considering the prehistoric evidence of strong earthquakes with epicenters within Indiana, the history of earthquakes that have caused damage in Indiana since 1811, and the presence of compressional forces squeezing the rocks at great depths under the state, it is reasonable to conclude that Indiana may experience the potentially devastating effects of a major earthquake in the future.

Assessment of a dam's risk from seismic loading requires a thorough understanding of the local geology and the engineering properties of the foundation and embankment soils. If there are safety issues with the stability of the slopes, embankment, or spillway structure of an existing dam, seismic loading will only exacerbate the problem.

Mining Issues

Mineral and fuel commodities mined in Indiana include common clay and shale, limestone and dolomite, construction sand and gravel, industrial sand, sandstone, gypsum, peat, and coal. There are over 300 current mines in operation and hundreds of abandoned mines.

The main issues with mining that may impact the safety of an existing dam are abandoned underground unstable mines, dramatically altered watersheds from surface mining, and/or operations such as blasting from nearby working mines. The dam itself may have been a result of a temporary mining operation with questionable materials used to construct the embankment and undersized spillway to handle small runoff events. The inspector should thoroughly investigate all geological sources to develop appropriate plans and recommendations, if the dam is near an abandoned or existing mining operation.

Any questions, comments, concerns, or fact sheet requests should be directed to the Division of Water at the following address:

Indiana Department of Natural Resources
Division of Water
402 West Washington Street
Indianapolis, Indiana 46204
(317) 232-4160 (Voice) (317) 233-4576 (Fax)
http://www.in.gov/dnr/water

Additional Resources

Indiana Geological Survey, *Physiographic Divisions of Indiana,* H.H. Gray, 2000, Indiana Geological Survey Special Reports, SR61, 611 North Walnut Grove, Bloomington, IN 47405-2208

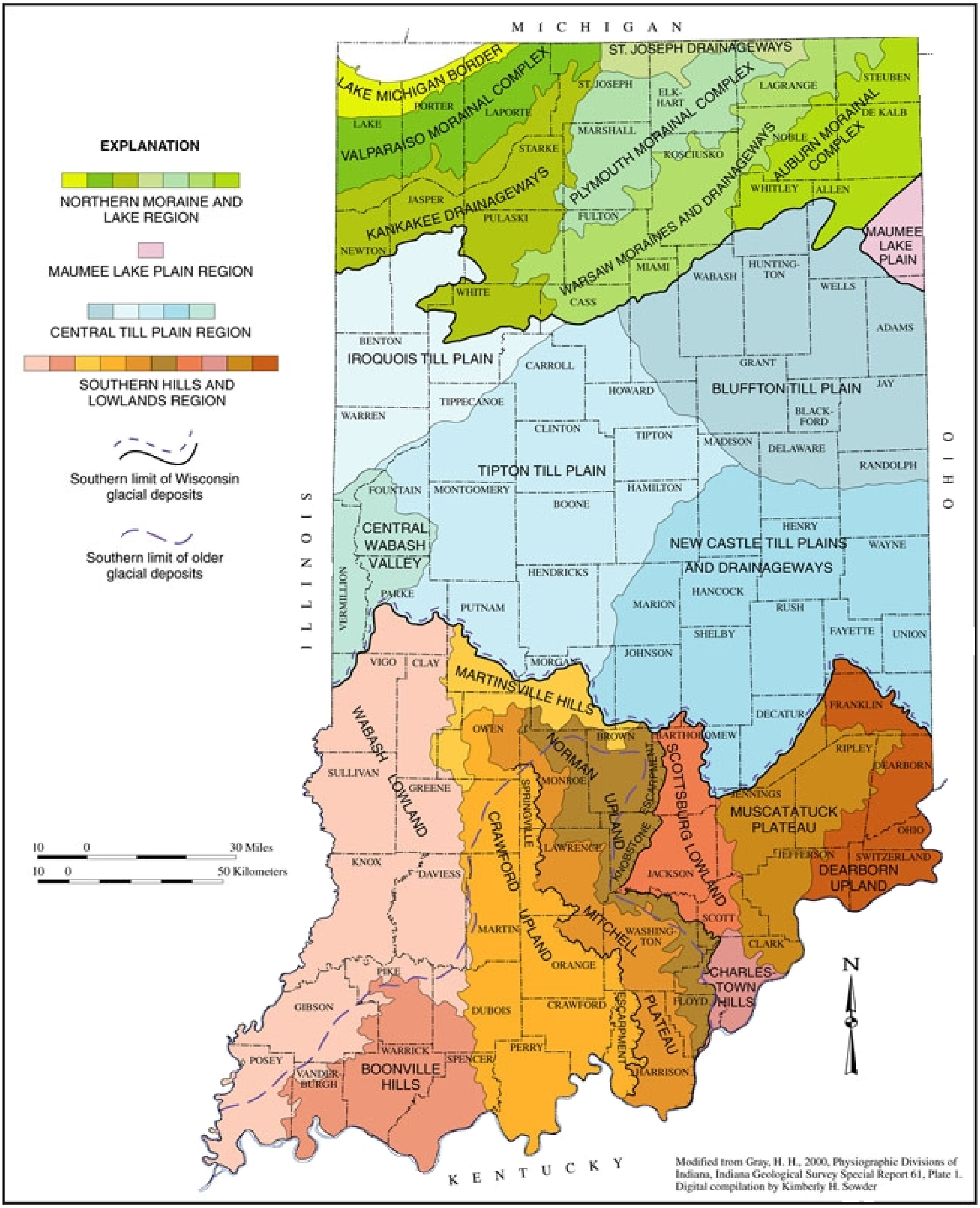

Figure 1 - Physiographic Divisions of Indiana

Table 1 - Typical geologic factors by Physiographic Divisions that may influence the integrity, safety, upgrade, and operation of an existing dam

Northern Moraine & Lake Region	1.a	1.b	1.c	1.d	1.e	1.f	1.g	1.h	1.i	1.j	1.k	1.l	1.m	1.n	2.a	2.b	2.c	2.d	2.e	2.f	2.g	2.h
Lake Michigan Border																	X			X		
Valparaiso Morainal Complex																	X	X		X		X
Kankakee Drainageways																X	X	X	X	X		X
St. Joseph Drainageways																	X	X	X	X		X
Plymouth Morainal Complex															X	X	X	X	X	X		X
Warsaw Moraines & Drainageways															X	X	X	X	X	X		X
Auburn Morainal Complex															X		X	X		X		
Maumee Lake Plain Region																						
Central Till Plain Region																						
Bluffton Till Plain							3													X		
Iroquois Till Plain							3													X		
Tipton Till Plain							3													X		
New Castle Till Plains & Drainageways							3										X			X		
Central Wabash Valley											X	X	X								X	
Southern Hills & Lowlands Region																						
Wabash Lowland											X	X	X	X			X				X	
Boonville Hills			X					X		X	X	X	X	X							X	
Martinsville Hills		X		X	X																	
Crawford Upland	X	X		X	X		X	X	X	X												
Mitchell Plateau	X	X				X		X		X												
Norman Upland	X	X	X	X	X			X	X	X				X								
Scottsburg Lowland (except Brownstown Hills)																	X				X	
Charlestown Hills			X					X		X												
Muscatatuck Plateau	X	X	X	X	X		X	X		X				X			X					
Dearborn Upland	X	X	X	X	X			X	X	X				X								

See notes on following page for clarification.

<u>Notes for Table 1:</u>

1. <u>Definitions for columns labeled 1.a through 1.n.</u>

a. Unconsolidated material over steep sloping, valley bedrock surface, instability potential at the dam, spillway or around lake.

b. Steep valley walls, difficult to prepare site for construction or expansion of emergency spillway. Seepage at abutment contact, erosion at groin area and/or long term settlement likely.

c. Near surface non-durable bedrock. Weak rock materials may have been used in embankments which disintegrate/collapse with time causing settlement, sloughing and instability of the dam.

d. Rugged watersheds & downstream areas. Quick peak flows into lake. Erosion potential. Confined, fast flows during discharge or an uncontrolled breach.

e. Steep gradient tributaries require tall embankment dams for small lakes and ponds. High water pressures exist at base of dam; downstream embankment slopes extend a considerable distance.

f. Extensive karst development (sinkholes, large subsurface voids and openings for uncontrolled water movement, loss and gain of overland flow) present significant dam safety issues.

g. Some karst development that leads to uncontrolled leakage in foundation and/or abutment.

h. Jointed, fractured rock provides paths of seepage after infilling material softens and erodes out with time.

i. Access for emergency response more difficult than less rugged areas.

j. Near surface rock limits borrow material quantities for upgrade on embankment and increases cost for excavation.

k. Old mine works: Subsurface abandoned coal mines & long-term subsidence threaten integrity of dams & spillways. Acidic runoff detrimental to metal spillway pipes.

l. Current/future coal mining: consideration to blasting, undermining, major alterations to watershed and drainage ways. Acidic runoff detrimental to metal spillway pipes.

m. Seismic, ground acceleration, loss of soil strength due to liquefaction.

n. Foundation rock may consist of weathered shale/claystone that, after a time of saturation, looses strength resulting in slippage planes and instability of embankment.

2. <u>Definitions for columns labeled 2.a through 2.h.</u>

a. May be associated with natural fresh water lakes; draw down for repair and emergency potentially hindered due to legal lake levels, wetlands, and sediment releases.

b. Large, broad areas where time of flood peak is attenuated, breach flood is wide, shallow & irregular due to low saddles between drainage divide & wetlands.

c. Permeable unconsolidated materials in foundation and/or embankment, substantial seepage potential.

d. Soft, deep organic deposits in foundation result in instability and settlement. Increasing height is difficult due to unsuitable foundation soils.

e. Significant interaction between subsurface ground-water regime and surface watershed that impacts spillway design and operation.

f. Non-plastic soils, erosion potential high on embankment, spillway and discharge areas.

g. Embankment, foundation and/or abutments may contain significant amounts of loess (silt), which has poor engineering properties (low strength, liquefaction, erodes, etc.)

h. High variability of soil types and conditions at local sites. Complex.

3. Bedrock may be encountered in certain local areas in these districts. Geologic factors 1g, 1h, & 1j may apply in those shallow bedrock areas.